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Neutrosophic Z-Number Analysis of Music Therapy Effects on Lower Limb Muscle Strength in Type 2 Diabetes Mellitus Patients

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Abstract

This study evaluates the impact of music-assisted strength training on lower limb muscle performance in patients with Type 2 Diabetes Mellitus (T2DM), applying Neutrosophic Z-Numbers (NZNs) to model subjectivity and uncertainty in clinical data. T2DM, characterized by insulin resistance and musculoskeletal decline, often reduces mobility and increases fall risk. In a Randomized Controlled Trial (RCT) involving 30 participants, an experimental group underwent music-supported exercise sessions, while the control group received no intervention. Patient evaluations were encoded using NZNs to quantify subjective assessments, which capture truth, indeterminacy, and falsity—each paired with a reliability measure. These were aggregated and statistically analyzed via a modified Mann–Whitney U test. The findings revealed significant improvements ($p < 0.05$) in the intervention group's hip and knee extensor strength. This study highlights the dual contribution of music-based interventions to physical and emotional well-being. It showcases the potential of NZNs in enhancing the interpretability of imprecise health data in rehabilitation settings.

Keywords: Neutrosophic Z-number, Subjective assessment, Music therapy, T2DM, Mann–whitney U test, Uncertainty modeling.

1 | Introduction

Type 2 Diabetes Mellitus (T2DM) is a primary global health concern that affects over 422 million people worldwide, with projections estimating 693 million cases by 2045 [1]. T2DM is primarily associated with insulin resistance, chronic inflammation, and oxidative stress, leading to muscular weakness, particularly in the lower limbs. This muscular decline contributes to mobility impairments, increased risk of falls, and reduced quality of life [2].

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Strength training interventions have been shown to improve muscle mass, strength, and physical function in T2DM patients. Recent studies have also highlighted the benefits of combining exercise with music therapy, which can enhance motivation, adherence, and outcomes in clinical rehabilitation [3], [4]. This integrative approach has shown potential in improving HbA1c levels, neuromuscular function, balance, and emotional well-being. In Ecuador, according to the results of the National Health and Nutrition Survey (ENSANUT in Spanish), the prevalence of diabetes in the population aged 10 to 59 is 1.7% [5]. This proportion tends to increase with age, reaching a significant peak at age 50, where one in ten Ecuadorians already has diabetes, according to research data. Strength training combined with music therapy has been shown to improve glycated Hemoglobin A1c (HbA1c) levels, increase muscle mass, strength, joint range of motion, balance, communication, and cognition, as well as better performance when performing activities such as sitting or standing, providing individuals with a better quality of life in patients diagnosed with T2DM.

This intervention is necessary because people with T2DM develop sarcopenic or musculoskeletal deterioration, decreasing their muscle mass, strength, and overall functionality. The lower limbs are designed to be crucial to the human body's functionality, balance, and locomotor capacity. They also house important vascular and nervous structures essential for blood circulation and neuromuscular connectivity. Therefore, any alteration in the health of the lower limb, like injuries, pathologies, or chronic conditions such as T2DM, would significantly affect the quality of life of these individuals. Therefore, understanding the importance of the lower limb, not only from an anatomical and functional perspective but also in terms of its relevance to overall health, is essential for an appropriate approach to addressing medical and rehabilitation needs. For this reason, this project will result in the design of a therapeutic plan for muscle strength focused on the lower limbs using music therapy. Implementing specific exercises to strengthen the lower limb muscles improves overall physical function and adaptation to these therapeutic protocols. It plays a key role in regulating glucose levels.

By combining this strategy with music therapy, adherence to exercise programs can be encouraged, resulting in greater muscle strength, a normal range of joint motion, and consequently improved blood circulation in the lower extremities. This reduces the risks associated with diabetes, such as muscle weakness, obesity, circulatory problems, and tissue complications. The integration of music therapy into diabetes care has garnered increasing interest due to its potential to enhance both physiological and psychological outcomes. Eseadi and Amedu [1] conducted a descriptive review titled "potential impact of music interventions in managing diabetic conditions," identifying six eligible studies through bibliographic screening. Their analysis suggested that combining music with physical activity can significantly improve exercise adherence, enhance peripheral blood circulation, reduce glucose and stress levels, and contribute to an overall health balance in T2DM patients.

Nevertheless, the authors emphasized the limited number of Randomized Controlled Trials (RCTs) and called for further high-quality investigations with larger sample sizes and robust methodological designs [6]. In another RCT, Chien et al. [7] assessed the effects of a 12-week progressive resistance training program using sandbags in older adults diagnosed with T2DM and probable sarcopenia. Forty participants were randomly assigned to intervention and control groups. Post-intervention results revealed significant improvements in HbA1c levels, muscle strength, and physical function in the intervention group, highlighting the efficacy of resistance-based interventions in glycemic control and functional mobility. Similarly, Witusik et al. [8] conducted a systematic review to evaluate the role of music therapy in managing T2DM. Their analysis pointed to favorable psychological and behavioral outcomes. However, the scarcity of standardized clinical trials limits the generalizability of the findings. The study recommended that future research should adopt rigorous protocols, objective endpoints, and larger, more diverse populations to validate the clinical application of music therapy in diabetic care.

While a wide range of studies has explored exercise-based interventions for patients with T2DM, integrating music therapy into strength training remains a largely unexplored domain, especially when evaluated through rigorous mathematical frameworks designed to capture uncertainty and subjectivity in clinical

outcomes. This study proposes a novel interdisciplinary approach with three primary objectives: 1) to evaluate the impact of music-supported strength training on lower limb muscle strength in patients with T2DM, 2) to demonstrate the applicability of Neutrosophic Z-numbers (NZNs) in capturing indeterminacy in subjective health assessments, and 3) to develop a scalable and adaptable therapeutic protocol suitable for resource-constrained healthcare environments. The direct beneficiaries of this intervention are T2DM patients residing in Atahualpa parish, while the broader population - including healthcare providers and physiotherapists - stands to benefit from the clinical insights and protocols developed through this research. The innovative nature of this project stems from its fusion of conventional physical therapy with music therapy, a combination rarely explored in diabetes care. The resulting evidence is expected to provide meaningful contributions to the fields of physiotherapy, health informatics, and rehabilitative sciences.

This research is supported by the Technical University of Ambato (TUA) and aligned with its strategic research line "interventions: Treatment techniques and protocols." The institutional backing ensures the study's feasibility and ethical compliance. Data collected from both experimental and control groups were initially analyzed using classical statistical methods such as the Mann-Whitney U test. However, we wanted to obtain data that included the indeterminacy and uncertainty inherent in all measurements. This is because the measurements were based on symptoms, signs, and perceptions, which are characterized by the subjectivity of both the subject and the evaluator. One option could be using Neutrosophic Statistics or Plithogenic Statistics [9-15]. However, recognizing the limitations of these tools in capturing subjective variability, this study advances the methodology by incorporating NZNs - an advanced tool for modeling imprecision and ambiguity inherent in clinical evaluations [16-19]. NZNs extend Zadeh's original concept of Z-numbers [20] by integrating the principles of Neutrosophic logic. In this framework, each assessment is represented as a triplet: 1) degrees of truth, 2) indeterminacy, and 3) falsity, with an added reliability index for each component. This layered representation offers more nuanced and realistic modeling of human-centric clinical data, mainly when evaluations rely on perception, expert opinion, or semi-quantitative judgment [21].

Historically, fuzzy set theory introduced by Zadeh [22] initiated the formal modeling of uncertainty by assigning membership grades within the interval [0, 1]. This foundational idea was later expanded through Atanassov's intuitionistic fuzzy sets, which introduced non-membership functions and the concept of hesitation [23]. Smarandache further advanced the field by proposing Neutrosophic Sets (NSs), which explicitly account for indeterminacy, relax constraints on the sum of truth, falsity, and indeterminacy values, and attract various scholars [24-34]. Zadeh's Z-numbers were then developed to capture not only the degree of truth of a statement but also the confidence or reliability associated with it. This dual structure provided a mechanism to model subjective information more comprehensively. NZNs synthesize these developments by embedding reliability into each component of a Neutrosophic triplet, making them particularly useful for healthcare applications where subjective judgments are pervasive. These constructs have grown applications in medical domains, such as clinical diagnostics, medical imaging, and treatment planning. Their ability to represent ambiguity, inconsistency, and partial knowledge makes them suitable for decision-making under uncertainty in health sciences [35-40]. Recent literature reports their usage in bioinformatics, patient stratification, and intelligent decision support systems.

In this study, outcome data - based on patients' perceived strength and functional improvement - were encoded as NZNs and subjected to a modified Mann-Whitney U test to assess inter-group differences. This modeling approach acknowledges the subjective nature of patient-reported outcomes and reduces evaluative bias through a reliability-weighted scoring system. In summary, the novelty of this research lies in its fusion of music therapy with physiotherapeutic strength training, evaluated through the advanced modeling capabilities of NZNs. This approach not only addresses the inherent subjectivity in clinical rehabilitation studies but also sets the stage for more precise and reliable therapeutic assessments in future healthcare research.

The remainder of the paper is structured as follows. Section 3 presents the theoretical foundations and mathematical properties of NZNs. Section 4 describes the study design, experimental protocol, and

computational procedures. Section 5 discusses the results and implications, while Section 6 concludes the study and outlines directions for future research. Supplementary exercise protocols are provided in the Appendix.

2 | Preliminaries

This section contains the main concepts used in this paper; let us begin with the formal definition of Z-number, NS, Single-Valued NS, and NZN.

Definition 1 ([20], [21]). A Z-number is an ordered pair $Z = (A, R)$ of fuzzy numbers, where A is the fuzzy restriction on the values taken in the evaluation, whereas R is the reliability of A. R could represent confidence, strength of belief, probability, possibility, or alike.

Z-numbers model sentences of the type (Population of Spain, about 45 million, quite sure) or (The price of oil in the near future, significantly over 100 dollars/barrel, very likely) [33].

Definition 2 ([27]). Let X be a universe of discourse. A NS is characterized by three membership functions, $u_A(x), r_A(x), v_A(x) : X \rightarrow \left]^-0, 1^+\right[$, which satisfies the condition $^-0 \leq \inf u_A(x) + \inf r_A(x) + \inf v_A(x) \leq \sup u_A(x) + \sup r_A(x) + \sup v_A(x) \leq 3^+$ for all x∈X. $u_A(x), r_A(x)$ and $v_A(x)$ are the membership functions of truthfulness, indeterminacy, and falseness of x in A, respectively, and their images are standard or non-standard subsets of $\left]^-0, 1^+\right[$.

Definition 3 ([31]). Let X be a universe of discourse. A Single-Valued Neutrosophic Set (SVNS) A on X is a set of the form:

$$A = \{\langle x, u_A(x), r_A(x), v_A(x)\rangle : x \in X\}, \quad (1)$$

where $u_A, r_A, v_A : X \rightarrow [0,1]$, satisfy the condition $0 \leq u_A(x) + r_A(x) + v_A(x) \leq 3$ for all x∈X. $u_A(x), r_A(x)$ and $v_A(x)$ denote the membership functions of truthfulness, indeterminacy, and falseness of x in A, respectively. For convenience, a Single-Valued Neutrosophic Number (SVNN) will be expressed as $A = (a, b, c)$, where $a, b, c \in [0,1]$ and satisfy $0 \leq a + b + c \leq 3$.

Definition 4 ([17]). Let X be a universe set. A NZN set in X is defined as follows:

$$S_Z = \{\langle x, T(V, R)(x), I(V, R)(x), F(V, R)(x)\rangle : x \in X\}, \quad (2)$$

where $T(V, R)(x) = \left(T_V(x), T_R(x)\right)$, $I(V, R)(x) = \left(I_V(x), I_R(x)\right)$, $F(V, R)(x) = \left(F_V(x), F_R(x)\right)$ are maps from X to $[0, 1]^2$, which are the ordered pairs or truth, indeterminacy, and falsity, respectively. The first component V is the neutrosophic values in X, and the second component R is the neutrosophic measures of reliability for V, satisfying the conditions $0 \leq T_V(x) + I_V(x) + F_V(x) \leq 3$ and $0 \leq T_R(x) + I_R(x) + F_R(x) \leq 3$.

For convenience, we denote $\langle x, T(V, R)(x), I(V, R)(x), F(V, R)(x)\rangle$ as $S_Z = \langle T(V, R), I(V, R), F(V, R)\rangle = \langle (T_V, T_R), (I_V, I_R), (F_V, F_R)\rangle$ which is named NZN.

Definition 5 ([17]). Let $S_{Z_1} = \langle T_1(V, R), I_1(V, R), F_1(V, R)\rangle = \langle \left(T_{V_1}, T_{R_1}\right), \left(I_{V_1}, I_{R_1}\right), \left(F_{V_1}, F_{R_1}\right)\rangle$ and $S_{Z_2} = \langle T_2(V, R), I_2(V, R), F_2(V, R)\rangle = \langle \left(T_{V_2}, T_{R_2}\right), \left(I_{V_2}, I_{R_2}\right), \left(F_{V_2}, F_{R_2}\right)\rangle$ be two NZNs and $\lambda > 0$. Then we give the following relations:

I. $S_{Z_2} \subseteq S_{Z_1} \Leftrightarrow T_{V_2} \leq T_{V_1}, T_{R_2} \leq T_{R_1}, I_{V_1} \leq I_{V_2}, I_{R_1} \leq I_{R_2}, F_{V_1} \leq F_{V_2}, F_{R_1} \leq F_{R_2}$.

II. $S_{Z_1} = S_{Z_2} \Leftrightarrow S_{Z_2} \subseteq S_{Z_1}$ and $S_{Z_1} \subseteq S_{Z_2}$.

III. $S_{Z_1} \cup S_{Z_2} = \langle \left(T_{V_1} \vee T_{V_2}, T_{R_1} \vee T_{R_2}\right), \left(I_{V_1} \wedge I_{V_2}, I_{R_1} \wedge I_{R_2}\right), \left(F_{V_1} \wedge F_{V_2}, F_{R_1} \wedge F_{R_2}\right)\rangle$.

IV. $S_{Z_1} \cap S_{Z_2} = \langle \left(T_{V_1} \wedge T_{V_2}, T_{R_1} \wedge T_{R_2}\right), \left(I_{V_1} \vee I_{V_2}, I_{R_1} \vee I_{R_2}\right), \left(F_{V_1} \vee F_{V_2}, F_{R_1} \vee F_{R_2}\right)\rangle$.

V. $\left(S_{Z_1}\right)^c = \langle \left(F_{V_1}, F_{R_1}\right), \left(1 - I_{V_1}, 1 - I_{R_1}\right), \left(T_{V_1}, T_{R_1}\right)\rangle$.

VI. $S_{Z_1} \oplus S_{Z_2} = \langle \left(T_{V_1} + T_{V_2} - T_{V_1}T_{V_2}, T_{R_1} + T_{R_2} - T_{R_1}T_{R_2}\right), \left(I_{V_1}I_{V_2}, I_{R_1}I_{R_2}\right), \left(F_{V_1}F_{V_2}, F_{R_1}F_{R_2}\right)\rangle$.

VII. $S_{Z_1} \otimes S_{Z_2} = \langle (T_{V_1}T_{V_2}, T_{R_1}T_{R_2}), (I_{V_1}+I_{V_2} - I_{V_1}I_{V_2}, I_{R_1}+I_{R_2} - I_{R_1}I_{R_2}), (F_{V_1}+F_{V_2} - F_{V_1}F_{V_2}, F_{R_1} + F_{R_2} - F_{R_1}F_{R_2}) \rangle$.

VIII. $\lambda S_{Z_1} = \langle \left(1-(1-T_{V_1})^{\lambda}, 1-(1-T_{R_1})^{\lambda}\right), (I_{V_1}^{\lambda}, I_{R_1}^{\lambda}), (F_{V_1}^{\lambda}, F_{R_1}^{\lambda}) \rangle$.

IX. $S_{Z_1}^{\lambda} = \langle (T_{V_1}^{\lambda}, T_{R_1}^{\lambda}), \left(1-(1-I_{V_1})^{\lambda}, 1-(1-I_{R_1})^{\lambda}\right), \left(1-(1-F_{V_1})^{\lambda}, 1-(1-F_{R_1})^{\lambda}\right) \rangle$.

To compare two NZNs having $S_{Z_i} = \langle T_i(V,R), I_i(V,R), F_i(V,R) \rangle = \langle (T_{V_i}, T_{R_i}), (I_{V_i}, I_{R_i}), (F_{V_i}, F_{R_i}) \rangle$ (i = 1, 2), we have the score function:

$$\Upsilon(S_{Z_i}) = \frac{2+T_{V_i}T_{R_i}-I_{V_i}I_{R_i}-F_{V_i}F_{R_i}}{3}. \tag{3}$$

Let us note that $\Upsilon(S_{Z_i}) \in [0,1]$. Therefore, $\Upsilon(S_{Z_2}) \leq \Upsilon(S_{Z_1})$ implies $S_{Z_2} \preccurlyeq S_{Z_1}$.

Let us illustrate *Eq. (3)* with an example.

Example 1. Let $S_{Z_1} = \langle (0.9, 0.8), (0.1, 0.9), (0.2, 0.9) \rangle$, then we have $\Upsilon(S_{Z_1}) = \frac{2+(0.9)(0.8)-(0.1)(0.9)-(0.2)(0.9)}{3} = 0.81666$.

Definition 6 ([19]). Let $S_{Z_i} = \langle T_i(V,R), I_i(V,R), F_i(V,R) \rangle = \langle (T_{V_i}, T_{R_i}), (I_{V_i}, I_{R_i}), (F_{V_i}, F_{R_i}) \rangle$ (i = 1, 2, …, n) be a set of NZNs and NZNWAA is a map from $[0,1]^n$ in $[0,1]$, such that the NZNWAA operator is defined as follows:

$$\mathrm{NZNWAA}(S_{Z_1}, S_{Z_2}, \cdots, S_{Z_n}) = \sum_{i=1}^{n} \lambda_i S_{Z_i}, \tag{4}$$

where λ_i $(i = 1,2,\cdots,n)$ is the weight of S_{Z_i} satisfying $0 \leq \lambda_i \leq 1$ and $\sum_{i=1}^{n} \lambda_i = 1$.

Thus the formula of the NZNWAA is calculated as:

$$\mathrm{NZNWAA}(S_{Z_1}, S_{Z_2}, \cdots, S_{Z_n}) = \langle \left(1-\prod_{i=1}^{n}(1-T_{V_i})^{\lambda_i}, 1-\prod_{i=1}^{n}(1-T_{R_i})^{\lambda_i}\right), \left(\prod_{i=1}^{n} I_{V_i}^{\lambda_i}, \prod_{i=1}^{n} I_{R_i}^{\lambda_i}\right), \left(\prod_{i=1}^{n} F_{V_i}^{\lambda_i}, \prod_{i=1}^{n} F_{R_i}^{\lambda_i}\right) \rangle. \tag{5}$$

NZNWAA satisfies the following properties:

I. It is an NZN.

II. It is idempotent, $\mathrm{NZNWAA}(S_Z, S_Z, \cdots, S_Z) = S_Z$.

III. Boundedness, $\min\{S_{Z_1}, S_{Z_2}, \cdots, S_{Z_n}\} \leq \mathrm{NZNWAA}(S_{Z_1}, S_{Z_2}, \cdots, S_{Z_n}) \leq \max\{S_{Z_1}, S_{Z_2}, \cdots, S_{Z_n}\}$.

IV. Monotonicity, if for all i $S_{Z_i} \preccurlyeq S_{Z_i}^*$ then $\mathrm{NZNWAA}(S_{Z_1}, S_{Z_2}, \cdots, S_{Z_n}) \preccurlyeq \mathrm{NZNWAA}(S_{Z_1}^*, S_{Z_2}^*, \cdots, S_{Z_n}^*)$.

Definition 7 ([19]). Let $S_{Z_i} = \langle T_i(V,R), I_i(V,R), F_i(V,R) \rangle = \langle (T_{V_i}, T_{R_i}), (I_{V_i}, I_{R_i}), (F_{V_i}, F_{R_i}) \rangle$ (i = 1, 2, …, n) be a set of NZNs and NZNWGA is a map from $[0,1]^n$ in $[0,1]$, such that the NZNWGA operator is defined as follows:

$$\mathrm{NZNWGA}(S_{Z_1}, S_{Z_2}, \cdots, S_{Z_n}) = \sum_{i=1}^{n} S_{Z_i}^{\lambda_i}, \tag{6}$$

where λ_i $(i = 1,2,\cdots,n)$ is the weight of S_{Z_i} satisfying $0 \leq \lambda_i \leq 1$ and $\sum_{i=1}^{n} \lambda_i = 1$.

Thus the formula of the NZNWGA is calculated as

$$\mathrm{NZNWGA}(S_{Z_1}, S_{Z_2}, \cdots, S_{Z_n}) = \langle \left(\prod_{i=1}^{n} T_{V_i}^{\lambda_i}, \prod_{i=1}^{n} T_{R_i}^{\lambda_i}\right), \left(1-\prod_{i=1}^{n}(1-I_{V_i})^{\lambda_i}, 1-\prod_{i=1}^{n}(1-I_{R_i})^{\lambda_i}\right), \left(1-\prod_{i=1}^{n}(1-F_{V_i})^{\lambda_i}, 1-\prod_{i=1}^{n}(1-F_{R_i})^{\lambda_i}\right) \rangle. \tag{7}$$

NZNWGA satisfies the following properties:

I. It is an NZN.

II. It is idempotent, $\mathrm{NZNWGA}(S_Z, S_Z, \cdots, S_Z) = S_Z$.

III. Boundedness, $\min\{S_{Z_1}, S_{Z_2}, \cdots, S_{Z_n}\} \leq \mathrm{NZNWGA}(S_{Z_1}, S_{Z_2}, \cdots, S_{Z_n}) \leq \max\{S_{Z_1}, S_{Z_2}, \cdots, S_{Z_n}\}$.

IV. Monotonicity, if for all i $S_{Z_i} \preccurlyeq S^*_{Z_i}$ then $\mathrm{NZNWGA}(S_{Z_1}, S_{Z_2}, \cdots, S_{Z_n}) \preccurlyeq \mathrm{NZNWGA}(S^*_{Z_1}, S^*_{Z_2}, \cdots, S^*_{Z_n})$.

3 | Treatment Results

3.1 | Experimental Design

A random sample of 30 people belonging to the Senior Recreation Center of the Atahualpa GAD was taken and divided into two groups, one experimental and one control.

The criteria taken into account to be part of the experiment or not were the following:

Inclusion criteria:

I. Patients diagnosed with T2DM.

II. Sex: male or female.

III. People between 60 and 94 years old.

IV. People who have signed the informed consent.

V. People who do not have hearing problems.

Exclusion criteria:

I. People diagnosed with uncontrolled high blood pressure.

II. People who have had neuromusculoskeletal conditions of the lower limb during the last 3 months without a previous diagnosis.

III. People who have undergone surgery on the lower limb in the last 3 months.

IV. People who are absent from the treatment plan for three or more consecutive sessions.

The sample size of 30 was considered sufficiently large in statistical practice. Furthermore, once patients were excluded according to the exclusion criteria, the population was reduced to almost 30 individuals. We rounded the number to 30 so that specialists could work with a small number of individuals and provide personalized care. Individuals assigned to the experimental and control groups were randomly selected using simple random sampling. Due to the group size, it was impossible to assign a proportion of individuals according to age or gender.

This research project will be developed in the following phases:

Phase 1. An initial interview is conducted with the participants, in which the study topic, objectives, and assessments will be explained. Participants will be informed of how the results obtained during the study will be used, emphasizing that data will only be collected from those who voluntarily signed the informed consent form.

Phase 2. Subsequently, the respective assessments will be conducted on the Atahualpa Senior Recreation Center patients, beginning with collecting demographic data to identify any additional comorbidities they may present. The dynamometry test will then be started, and finally, the Senior Fitness Test (SFT) will be administered, focusing primarily on the item that assesses lower limb muscle strength. Each test will last between 20 and 30 minutes per participant. The muscle strength tests will be performed at the end of the intervention, and the results will be compiled in an Excel program. Below, we provide further details of the physiological tests that were applied.

The dynamometer manual is a first-class instrument needed for isometric muscle strength assessment. It is a valid, reliable, and practical method that can be adapted to the evaluator's needs. Currently, no standard testing positions have been determined for use with the hand-held dynamometer; however, evaluation positions with a high-reliability level demonstrated in previous studies will be used when assessing lower limb musculature.

To carry out the assessment, this device must be located at specific points on the limb being tested to quantify the force produced by different muscles or muscle groups. A study was done to analyze the reliability of several algorithms in calculating the force development rate. It included the analysis of interrater, interrater, and between devices of the dynamometry manual, besides investigating the validity concurrent with the dynamometry manual in assessing the force and isometric muscle power of the lower extremities. It was concluded that the reliability of manual dynamometry is in a range from good to excellent (coefficients ≥ 0.70) for all muscle groups; on the other hand, in terms of validity, results were obtained that range from moderate to excellent for hip and knee, and bad to good for ankle.

The physical battery of the SFT was developed to address the need for a tool that allows for a practical and safe assessment of the physical fitness of older adults. It is a comprehensive battery structured with several fitness components focused on functional independence. It can be applied to older adults between the ages of 60 and 94. It is relatively easy to use because it does not require technical equipment or clinical space. It also includes established reference values, which are vitally important when comparing data. The parameters assessed by the SFT are muscle strength, upper and lower limb flexibility, aerobic endurance, and agility.

Phase 3. The therapeutic plan focused on the lower limbs will be implemented, beginning with a warm-up combined with music therapy. Strength training exercises will then be applied using a set of resistance bands and weights. The planned exercises for the anterior and posterior muscles of the hip, thigh, and leg will be performed while listening to the respective musical intervention. Finally, a series of stretches will be performed. This protocol will be carried out for a period of 30 minutes, and two interventions will be performed weekly for a period of four months. The full schedule of lower limb exercises incorporated in the intervention is detailed in Appendix A (*Table A1*), including progression, duration, and muscle targets.

Each of the two experts, one for the control group and another one for the experimental group, was evaluated using the following methodology:

The coefficient of competence or suitability of experts is determined using the following formula:

$$\mathrm{K} = \frac{1}{2}(\mathrm{K_C} + \mathrm{K_a}), \tag{8}$$

where

K: is the coefficient of competition.

$\mathrm{K_C}$: is the coefficient of knowledge or information that the expert has on the subject.

$\mathrm{K_a}$: is the coefficient of argumentation or substantiation of the expert's criteria on the subject. This is self-rated as High (H), Medium (M), or Low (L).

- *It is High if* $K \geq 0.7$.
- *It is Medium if* $0.5 \leq K < 0.7$.
- *It is Low if* $0.3 \leq K < 0.5$.

For the experts' selection, only high levels Ks are accepted.

For more details on this coefficient, see [34].

Phase 4. Finally, a dynamometry assessment and the application of the Senior Fitness Test will be performed to identify the effects obtained during the treatment application.

The tests applied are evaluated according to the following scale of evaluation and reliability shown below:

Table 1. Linguistic truth and reliability values and their corresponding numerical value.

Linguistic Truth Value	Linguistic Reliability Value	Equivalent Numerical Value
Very Low	Very unsure	0.1
Low	Unsure	0.3
Middle	Neither sure nor unsure	0.5
High	Sure	0.7
Very High	Very Sure	0.9

Note that in *Table 1* we have linguistic values that specialists can use to make assessments. This corresponds to L. Zadeh's idea that humans evaluate with words rather than numbers. Furthermore, within the numerical scale, we ensure that the opposite of each value x corresponds to negation $n(x) = 1 - x$ (e.g., 0.3 means "unsure", while 0.7 = 1-0.3 means "sure"). The numerical values in each case are also symbolic, e.g., 0.3 is taken and not another value with more digits. This is because fuzziness consists of not seeking excessive numerical precision but rather symbolic precision.

The specialists are asked to formulate three pairs of values for each patient's performance regarding the proposed exercises. They are based on their assessments and measurements taken using traditional methods: the Senior Fitness Test and the dynamometry test.

For example, a specialist evaluates a patient p as satisfying the exercise called e with a Z-number equivalent to the pair (High, Sure). Or, in other words, he/she is "Sure" that p performs a "High" truth value; a linguistic Z-number of falsity (Very Low, Very Sure), that is, he/she is "Very Sure" that it is false, that p performs the exercise with a "Very Low" value; and with a linguistic Z-number of Indeterminacy (Low, Sure), that is, he/she is "Sure" that the indeterminacy has a "Low" level. Therefore, the equivalent numerical NZN is $\langle(0.7,0.7),(0.3,0.7),(0.1,0.9)\rangle$ according to the numerical values on the scale shown in *Table 1*.

So, we denote by $P_E = \{p_{e1}, p_{e2,\cdots,} p_{e15}\}$ the patients who are part of the experimental group, $P_C = \{P_{c1}, P_{c2,\cdots,} P_{c15}\}$ denote the patients who are part of the control group. The exercises to be evaluated with the Senior Fitness Test that will be practiced are the following:

- *Right hip flexors.*
- *Right knee extensor.*
- *Right knee flexor.*
- *Plantar flexor of right ankle.*
- *Right ankle dorsiflexion.*
- *Right hip abductors.*
- *Right hip adductor.*
- *Right hip extensor.*
- *Left hip flexors.*
- *Left knee extensor.*
- *Left knee flexor.*
- *Plantar flexor of left ankle.*
- *Dorsiflexors of the left ankle.*
- *Left hip abductors.*
- *Left hip adductor.*
- *Left hip extensor.*

For the experiment, the following procedure is performed:

I. The specialist evaluates the ith patient from the control group ($p_{ci} \in P_C$, $i = 1, 2, \dots, 15$) on their performance on the jth exercise ($p_{ei} \in P_E$, $i = 1, 2, \dots, 15$). Separately, another specialist evaluates the ith patient from the experimental group (e_j, $j = 1, 2, \dots, 16$) on their performance on the jth exercise (e_j,

$j = 1, 2, \dots, 16$). To do this, they use the linguistic values of the NZNs according to the scale shown in *Table 1*.

II. Let us call $x_{e_{ij}}$ the evaluation given by the specialist on the ith patient about the j[th] exercise in the experimental group. Similarly, $x_{c_{ij}}$ is the equivalent of the patients in the control group. Note that $x_{e_{ij}} = \langle (T_{V_{e_{ij}}}, T_{R_{e_{ij}}}), (I_{V_{e_{ij}}}, I_{R_{e_{ij}}}), (F_{V_{e_{ij}}}, F_{R_{e_{ij}}}) \rangle$ and $x_{c_{ij}} = \langle (T_{V_{c_{ij}}}, T_{R_{c_{ij}}}), (I_{V_{c_{ij}}}, I_{R_{c_{ij}}}), (F_{V_{c_{ij}}}, F_{R_{c_{ij}}}) \rangle$ are the measurement values in NZN form.

III. The values for each patient are aggregated for each group for all exercises. To do this, the NZNWAA aggregation operator shown in *Eq. (4)* is applied as $\bar{x}_{e_i} = \mathrm{NZNWAA}(x_{e_{i1}}, x_{e_{i2}}, \cdots, x_{e_{i16}})$ and $\bar{x}_{c_i} = \mathrm{NZNWAA}(x_{c_{i1}}, x_{c_{i2}}, \cdots, x_{c_{i16}})$, where $\lambda_j = \frac{1}{16}$, $j = 1, 2, \dots, 16$. Each exercise is part of the training system, so experts cannot identify one as more important than another, so they were all assigned the same weight in the aggregation.

IV. The obtained values of $\bar{x}_{e_i}$ and $\bar{x}_{c_i}$ are converted to single numerical values with the support of *Eq. (3)* by the following formulas: $\bar{\bar{x}}_{e_i} = \Upsilon(\bar{x}_{e_i})$ and $\bar{\bar{x}}_{c_i} = \Upsilon(\bar{x}_{c_i})$.

V. The Mann-Whitney U test is applied to the two groups of data $G_e = \{\bar{\bar{x}}_{e_i}\}$ and $G_c = \{\bar{\bar{x}}_{c_i}\}$.

Let us recall that the Mann-Whitney U test is based on the following equations [5]:

$$U_1 = n_1 n_2 + \frac{n_1(n_1 + 1)}{2} - R_1, \quad (9)$$

$$U_2 = n_1 n_2 + \frac{n_2(n_2 + 1)}{2} - R_2, \quad (10)$$

where n_1 is the sample size of one group, n_2 is the sample size of the other group, and R_1 and R_2 are the sum of the ranges of the observations in samples 1 and 2, respectively. Here $n_1 = n_2 = 15$.

The hypothesis test is as follows:

- *H0: Both populations are distributed equally and therefore the treatment does not produce significant improvements,*
- *H1: Both populations are distributed differently and therefore the treatment produces significant improvements.*

Recall that the Mann-Whitney U test is a statistical technique used to compare two independent samples when the data do not meet the requirements for a parametric test. The general steps to follow are as follows:

I. To define the hypothesis: The null hypothesis (H_0) is established, which indicates that there is no difference in the central tendency between the two groups, and also the alternative hypothesis (H_1), which suggests that there is a difference.

II. Sorting the data: The values from both samples are combined and ordered from lowest to highest. This article uses data in the form of NZN, and *Eq. (3)* allows for sorting. This is the advantage of using this method, as it allows us to work with ordinal values where actual measurements would otherwise have been required. Moreover, there is the advantage of not necessarily having the restriction of data normality.

III. Assign ranks: Each value in the sorted list is assigned a rank. If there are duplicate values, they are assigned the average of the corresponding ranks.

IV. Calculate the sum of ranks: The ranks of each group are added separately.

V. Calculate the statistic U: *Eqs. (9)* and *(10)* are used.

VI. Determine the critical value: Compare the lowest of the values between U_1 and U_2 -let us call it U- with the critical value of the Mann-Whitney distribution to evaluate statistical significance.

VII. Interpret the results: If the value of U is less than the critical value, the null hypothesis is rejected, indicating a significant difference between the groups.

This is the most appropriate statistical test for this experimental design. Other non-parametric tests, such as the Wilcoxon test, are used for paired samples, and the Kruskal-Wallis test is an extension of the Whitney-Mann test when comparing three or more groups of independent samples.

The significance level is set at 0.05. The results obtained are shown below.

3.2 | Results

We begin with the sociodemographic data of the experimental group, which is indicated in *Table 2*.

Table 2. Sociodemographic data experimental group.

Gender	Frequency	Percentage
Female	11	73%
Male	4	27%
Age Ranges	**Frequency**	**Percentage**
60-64	3	20%
65-69	5	33%
70-74	5	33%
75-79	1	7%
80-84	1	7%
85-89	0	0%
Diseases Added	**Frequency**	**Percentage**
Yes	15	100%
No	0	0%
Total	15	100%

Table 3 contains the sociodemographic details of the control group.

Table 3. Sociodemographic data control group.

Gender	Frequency	Percentage
Female	9	60%
Male	6	40%
Age Ranges	**Frequency**	**Percentage**
60-64	0	0%
65-69	8	53%
70-74	3	20%
75-79	2	13%
80-84	1	7%
85-89	1	7%
Diseases Added	**Frequency**	**Percentage**
Yes	15	100%
No	0	0%
Total	15	100%

Using the chi-square test of homogeneity, the frequencies of men and women in both groups are compared and it is found that there is no significant difference, here $\chi^2 = 3.07 < \chi^2_{0.95}(1) = 3.84$.

Regarding the age range $\chi^2 = 7.6 < \chi^2_{0.95}(4) = 9.49$; in this case, two age groups were aggregated to avoid division by 0. Likewise, there are no significant differences between both groups in terms of age range.

For diseases added, it is evident that there is no difference between groups.

The hired experts, one from each group, were evaluated with an expertise index of High, according to *Eq. (8)*.

The graphic representation can be seen in *Figs. 1* and *2*.

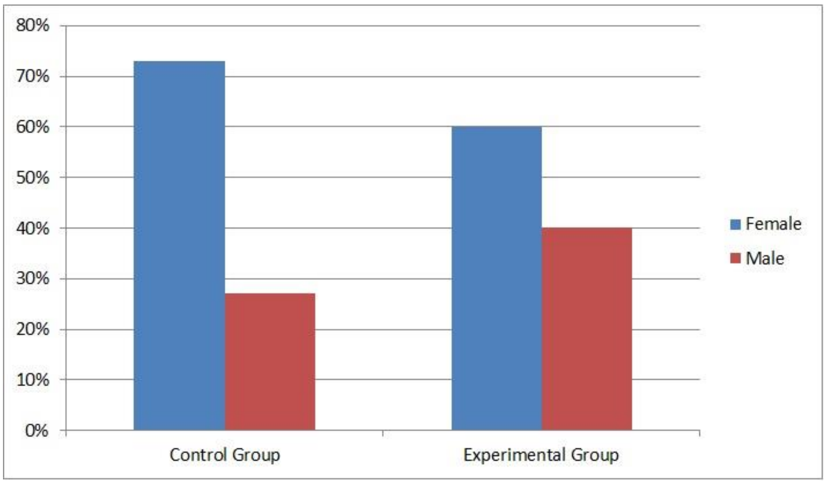

Fig. 1. Distribution of genders by each study group.

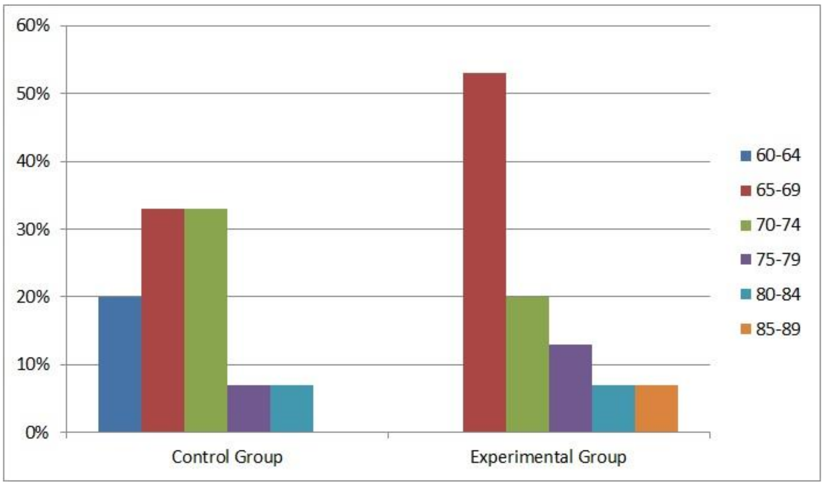

Fig. 2. Age ranges for each study group.

The p-value obtained after applying the procedure was $p = 0.034 < 0.05$. This is interpreted as rejecting H_0; therefore, the applied treatment significantly improves the patient's health.

4 | Discussion and Interpretation of Findings

The global burden of T2DM continues to escalate at an alarming pace. As of 2023, more than 590 million adults worldwide were living with diabetes, a figure projected to reach 853 million by 2050. More than 90% of these cases are attributed to T2DM, which is primarily driven by sedentary lifestyles, increasing obesity rates, and population aging. The World Health Organization (WHO) further reports that in 2022, diabetes prevalence had risen to over 830 million cases, with more than two million deaths associated with diabetes and its complications, such as diabetic nephropathy. These statistics underscore the urgency of developing innovative and sustainable T2DM prevention and management approaches.

In response to this challenge, the present study investigates the potential of integrating music-assisted strength training into rehabilitation programs for T2DM patients, particularly emphasizing lower limb functionality. Physical activity remains one of the most cost-effective and scalable interventions in diabetes care. However, adherence to structured exercise programs is often low. Music therapy has been shown to enhance patient motivation, emotional engagement, and compliance, making it a compelling adjunct to traditional rehabilitation. A significant methodological contribution of this study is the adoption of NZNs

as an analytic framework to model subjective and uncertain clinical data. NZNs combine the three membership components of NSs (truth, indeterminacy, and falsity) with the confidence scores inherent to Z-numbers, allowing for a more nuanced interpretation of patient-reported outcomes and clinician evaluations. Unlike classical statistical measures, which treat subjectivity as noise, NZNs capture and quantify the underlying uncertainty—thereby improving the fidelity of the assessment process. Clinical evaluation often involves multiple sources of variability: patients' descriptions of symptoms, healthcare providers' interpretations, and the limitations of objective biomarkers. The NZN-based model serves as a structured bridge between these domains, offering a hybrid representation that respects the complexity of real-world clinical judgments.

By converting linguistic evaluations into structured numerical triplets with reliability measures, the model captures the ambiguity inherent in musculoskeletal assessments in a diabetic context. Integrating NZNs introduced cognitive and procedural challenges for evaluators—especially in interpreting six-dimensional numerical representations—mitigated by implementing an intuitive linguistic scale. Each qualitative judgment was mapped to predefined numerical values, facilitating analysis while preserving interpretive richness. This strategy proved effective within the small sample framework of this study, though future research in larger cohorts may require further streamlining and training protocols to maintain evaluator consistency. Although traditional non-parametric methods such as the Mann–Whitney U test were used for baseline comparison, their integration with the NZN framework yielded enhanced interpretability and clinical relevance. The hybrid approach underscores the importance of merging quantitative rigor with qualitative insight in rehabilitation research.

In summary, this study demonstrates the applicability of NZNs in enhancing the sensitivity and reliability of clinical evaluations involving subjective criteria. The integration of music therapy into strength training regimens, assessed through this advanced analytic model, offers a promising avenue for patient-centered, data-informed diabetes care. Future studies should focus on refining the NZN framework, validating it across larger and more diverse populations, and expanding its application to other domains of chronic disease management.

5 | Conclusion

This study demonstrates the therapeutic efficacy of combining strength training with music therapy in improving lower limb muscle performance among individuals diagnosed with T2DM. Incorporating music with varying tempos-moderate, medium, and fast-served not only as a motivational aid but also contributed to participants' cognitive engagement and emotional well-being. These findings suggest that music-assisted exercise regimens can significantly enhance adherence and clinical outcomes in diabetic populations. A distinctive methodological advancement in this research was the application of NZNs in data analysis. Unlike conventional numerical data, NZNs allow uncertainty modeling by incorporating semantic dimensions-truth, indeterminacy, and falsity-each paired with a reliability metric. This approach proved highly effective in capturing the subjective nature of clinical assessments, particularly those involving patients' and clinicians' perceptions and qualitative observations. The statistical analysis was conducted using the non-parametric Mann–Whitney U test, providing a robust comparative framework combined with the depth of NZN-based modeling. The promising results of this study underscore the need for further research into integrating music therapy within chronic disease management protocols. Despite the limited number of prior investigations in this area, music's neurophysiological effects-such as modulation of the hypothalamic-pituitary-adrenal axis and influence on hormonal and metabolic regulation-warrant systematic exploration. Future studies should consider expanding sample sizes, diversifying patient demographics, and applying neutrosophic models to other domains of subjective healthcare evaluation. Overall, this research highlights the synergistic potential of interdisciplinary therapies and advanced uncertainty modeling techniques. The use of NZNs not only enhanced the analytical precision of clinical outcomes but also opened new avenues for the design of personalized and holistic treatment plans in diabetes care.

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Author Contribution

Conceptualization, L.J. Reales-Chacón, M.E. Lucena de Ustáriz, M.A. Valdiviezo-Maygua; Methodology, L.J. Reales-Chacón, M.E. Lucena de Ustáriz, M.A. Valdiviezo-Maygua, E.C. de la Torre-Nuñez; Formal analysis and investigation, L.J. Reales-Chacón, M.E. Lucena de Ustáriz, M.A. Valdiviezo-Maygua; Resources and data curation, E.C. de la Torre-Nuñez, F.J. Ustáriz-Fajardo, R.E. Cruz-Tenempaguay; Software and visualization, A.M. Monge-Moreno, S.M. Ortiz-Pérez, R.E. Cruz-Tenempaguay; Writing—original draft preparation, F.J. Ustáriz-Fajardo, R.E. Cruz-Tenempaguay, A.M. Monge-Moreno, S.M. Ortiz-Pérez; Supervision and project administration, L.J. Reales-Chacón; Funding acquisition, E.C. de la Torre-Nuñez, F.J. Ustáriz-Fajardo. All authors have read and agreed to the published version of the manuscript.

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Data Availability

No data is associated with this submission.

Conflicts of Interest

The authors declare no conflict of interest.

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Appendix

Table A1 contains some details of the treatment applied.

Table A1. Therapeutic plan for muscle strength in lower limbs with music therapy.

Exercises	Series	Music Therapy Active
Anteversion and Retroversion of the pelvis	1 set of 10 repetitions	Warm-up song. Music genre: Latin pop Characteristics: Medium tempo
Hip Circumduction	1 set of 10 repetitions per side	Warm-up song. Music genre: Latin pop. Characteristics: Medium tempo
Static march	1 set of 10 repetitions	Warm-up song. Music genre: Latin pop Characteristics: Medium tempo
Ankle Circumduction	1 set of 10 repetitions for each side and direction.	Warm-up song. Music genre: Latin pop Characteristics: Medium tempo
Squat	3 sets of 12 repetitions.	Training song. Music genre: Tropical music Characteristics: Moderate tempo
Side Steps	3 sets of 5 repetitions per side	Training song. Music genre: Tropical music Characteristics: Moderate tempo
Sumo Squat	2 sets of 10 repetitions	Training song. Music genre: Latin pop Features: Fast tempo
Lunges	3 sets of 10 repetitions on each side.	Training song. Music genre: Reggae. Characteristics: Medium tempo
Elevation of Knees	2 sets of 12 repetitions on each side.	Training song. Music genre: Reggae. Characteristics: Medium tempo
Gluteal Kick	3 sets of 12 repetitions per side.	Training song. Music genre: Tropical Music. Characteristics: Medium tempo
Tiptoes	3 sets of 12 repetitions per side.	Song of workout (medium tempo), song length 3:54 minutes
Hamstrings	1 set of 3 repetitions for 30 seconds each repetition.	Stretching song. Music genre: Pop. Features: Medium tempo
Adductors	1 set of 3 repetitions for 30 seconds each repetition per side.	Stretching song. Music genre: Pop. Features: Medium tempo
Quadriceps	1 set of 3 repetitions for 30 seconds each repetition per side.	Stretching song. Music genre: Pop. Characteristics: Medium tempo